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USE OF GPS DIFFERENTIAL NAVIGATION TECHNOLOGY IN CARINA CAPSULE REENTRY AND SPACE VEHICLE RENDEZVOUS OPERATIONS

by

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USE OF GPS DIFFERENTIAL NAVIGATION TECHNOLOGY IN CARINA CAPSULE REENTRY AND SPACE VEHICLE RENDEZVOUS OPERATIONS

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ABSTRACT

The Global Positioning System (GPS) will play a major role in space vehicle navigation and orbital determination. Absolute GPS navigation technology is applicable in the testing and practical stages of most space missions. Without ground any ground commands, GPS autonomous navigation uses independent methods to perform a number of on-board operations. This allows the amount of special ground facilities, and experimental data can be relayed to an earth station in a relatively short time.

By using the absolute measured values of two customers around a certain reference station as the differential to perform the relative navigation of the two customers, using differential technology it is possible to greatly reduce the effects of precision control (SA), the ionosphere, the troposphere and other slow varying errors. Because this technology can markedly improve the precision of orbital determination, it can be used in such operations as reentry and rendezvous.

This article will introduce the results of a feasibility study for the use of GPS for relative navigation between two space vehicles and space vehicle reentry orbit determination.

I. Using GPS for space vehicle autonomous navigation

A number of technologies have been studied for space vehicle navigation and orbital determination. Most of these are based on the model of special ground tracking equipment and space vehicle

coordinated operations. The constant increase in the numbers of space vehicles requires, on one hand, a corresponding increase in the numbers and capabilities of ground control stations, and on the other hand, autonomous navigation systems based on inertial equipment are unable to meet the precision requirements for the entire process of a space mission. Therefore, GPS autonomous navigation is needed because of the following three points:

(1). The increase in the numbers of space vehicles requires a corresponding growth in ground control. Autonomous navigation equipment can replace this increase in the number of ground stations.

(2). Conventional tracking systems cannot attain the positioning precision required by current space plants.

(3). If conventional tracking systems are continued to be used, space vehicles will have to maintain dynamics data, and normally will be forced to use extraordinary transmission methods to transmit results of ground orbit determination to the space vehicle. GPS navigation systems can allow the space vehicle to obtain in real time extremely precise dynamics data.

GPS satellite antenna direction designs must be able to ensure that customers on the ground, oceans and in space as well as space customers in orbit below 3000 kilometers are provided effective GPS services. GPS systems are very helpful for low altitude space vehicles, and can support the control functions of the following missions:

(1). Absolute and relative navigation for autonomous, live time independent movement and for rendezvous operations.

(2). Provide especially precise frequency and time reference systems, ensuring that the space vehicle is synchronous with ground control stations, and generating a stable communications carrier.

(3). Using composite navigation systems, it can precisely determine the attitude of a space vehicle. This comprehensive system includes a GPS receiver, an inertial platform, other special sensors and a special navigation processor.

GPS autonomous navigation systems will be used in support of a number of extremely important European space missions (such as the "Colombo" and "Hermes" as well as a number of national and international space programs.

This article introduces two research achievements of the Italian Space Administration using GPS navigation systems in support of two special low orbit missions.

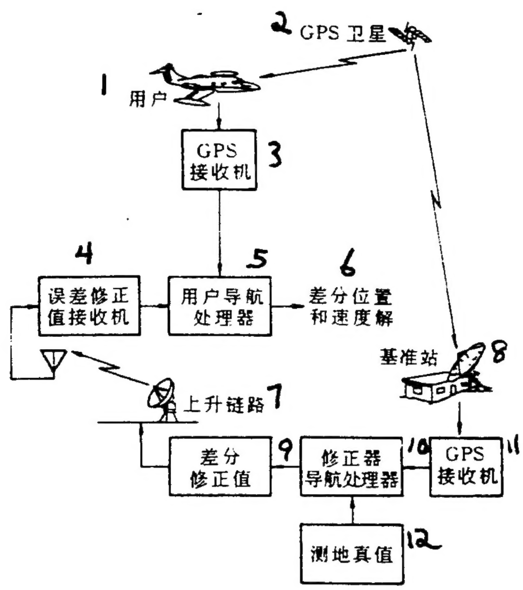
II. The concept of differential navigation

The principle of differential navigation is to compare the GPS signals received at two different locations in order to obtain more precise positioning data than with a GPS individual positioning technology.

The typical differential concept is the comprehensive use of the observed value measured by the customer flight vehicle and the observed value at the reference station. The reference station tracks the GPS satellite, and compares the positioning value with the known location of the reference station, determining the error in the false ranging measured value. Then, the calculated corrected value is provided to all customers within that reference stations

service area. Finally, the precision of the navigation solution is determined by the characteristics of the correction calculations used by the ground station's processor.

Fig. 1. The differential GPS concept



1. Customer. 2. GPS satellite. 3. GPS receiver. 4. Error correction value receiver. 5. Customer navigation processor. 6. Differential position and velocity. 7. Uplink. 8. Reference station. 9. Differential correction value. 10. Corrector navigation processor. 11. GOS receiver. 12. Actual geodesic value.

Figure 1 provides the ordinary principles of differential GPS positioning. The positioning precision provided by the GPS system can be improved greatly by using differential technology because the errors in the observed values of the two receivers can cancel each other out.

Under normal conditions, the major error sources of GPS ranging precision are:

1. GPS satellite clock error.
2. GOS satellite orbital error.
3. Precision control (SA).
4. Ionosphere transmission delay.
5. Troposphere transmission delay.
6. Receiver clock error.
7. Receiver noise.
8. Multipath effect.

Differential technology can reduce some of the effect of these error sources. Those errors which can be reduced or eliminated are those errors with strong spacial decorrelation between the customer and the reference station observed value. However, it cannot reduce the effects of receiver clock error and noise, because they are closely related to the characteristics of the receiver. the effects of the multipath effect are primarily determined by the customer's environment. Therefore, differential technology is not effective in reducing or eliminating this.

The primary improvements are seed in transmission error and those arising from the satellite. Comparing the pseudo observed data measured from two different receivers can completely correct the satellite clock error. The satellite close shift error and fixed deviation effects are the same for all customers tracking that satellite. As for satellite orbital error, in theory, it can only be markedly reduced for those customers very close, but the spacial correlation of this error is extremely weak.

Figure 2 describes the orbital error in relation to the geometric relationship between the customer and the differential station. The parameters within this figure are:

$\vec{e}_g$ = GPS satellite position error.

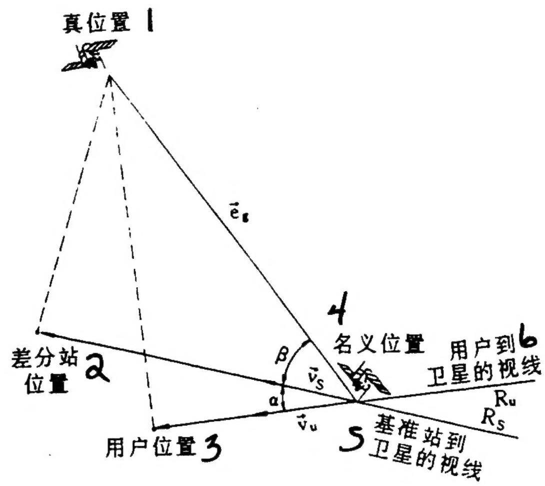
$\vec{v}_s$ = the distance unit vector from the GPS satellite to the differential station.

$\vec{v}_u$ = the distance unit vector from the GPS satellite to the customer.

α = the inclusive angle between $\vec{v}_s$ and $\vec{v}_u$.

β = the inclusive angle between $\vec{v}_s$ and $\vec{e}_g$

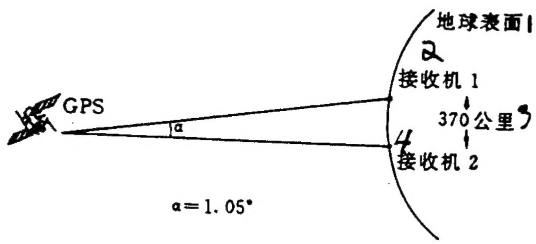
Fig. 2. Geometric relationship of orbital error



1. Actual position. 2. Differential station position. 3. Customer position. 4. Nominal position. 5. Visual line from reference station to satellite. 6. Visual line from customer to satellite.

Because the distant is very great from the satellite to the two receivers, the value of α is always extremely small (as shown in Figure 3). When the distance between the two receivers is 370 kilometers, the value if α os 1.05°.

Fig. 3 Geometric diagram of spacial angle α



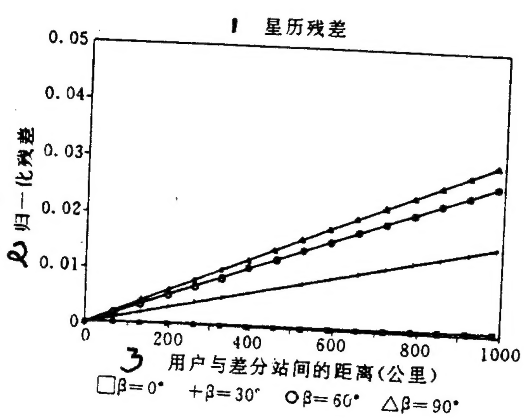
1. Surface of the earth. 2. Receiver 1. 3. 370 kilometers. 4. Receiver 2.

The remaining satellite orbital error in differential positioning can be calculated by the following formula:

$$e = e_{r_1} - e_{r_2} = |\vec{e}_r| [\cos\beta - \cos(\alpha + \beta)]$$

The most unfavorable situation is when angle β is 90°, that is, when the GPS satellite is directly over the differential station.

Fig. 4 Normalized Satellite residual error



1. Satellite residual error. 2. Satellite residual error. 3. Distance between customer and differential station (km)

Figure 4 shows the corresponding residual error value of the

angle β when the distance between the customer and the differential station increases. When the distance is less than several hundred kilometers, the normalized error value is less than thee percent.

The SA of the GPS satellite is the sum of the clock slow error and the orbital factor random error. The differential equation above can easily handle these two components of SA. For absolute navigation, SA will result in a 100 to 150 meter customer positioning error. When SA is added, it is the largest portion of the total error estimate. Therefore, the greatest advantage of differential navigation is that it can eliminate the artificial drop in precision caused by SA.

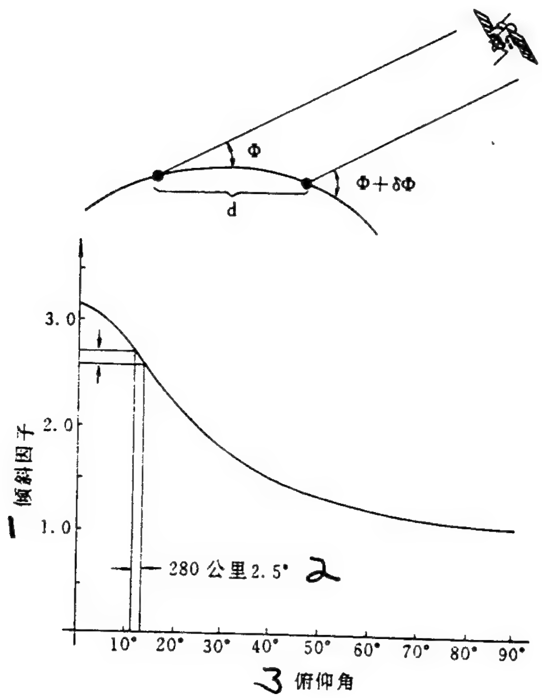
It is only when the customer is located very close by that differential technology can eliminate error caused by the transmission effect. Because the ionosphere and troposphere delay can be expressed as the product of a local vertical time delay factor and inclination factor, and these two factors both change over time and space, so spacial decorrelation is very strong.

As for P code customers, they can use dual frequency measurements to calculate and correct for ionospheric error, but tropospheric error cannot be eliminated by dual frequency methods. Civilian users of the C/A code are only able to use certain numerical or empirical models to correct for transmission error.

Figure five shows the changes in elevation angle $\theta$of the customer and differential station and the inclination factor values corresponding to different angles of elevation. When the customer and the differential station are 280 kilometers apart, the elevation angle differential is 2.5°. Under worst case conditions, when the differential station elevation angle is greater than 10 to 15°, the ionosphere delay residual layer is about six percent of

the total delay error.

Fig. 5. Different ionosphere errors: elevation angle and inclination factors



1. Inclination factor. 2. 280 kilometers 2.5°. 3. Elevation angle.

As for the troposphere delay, it can be modelled as the sum of "dry" and "wet" components. These two can described as a simple model, especially the "wet" component, the spacial correlation of which is not strong. No matter what the effect may be, differential technology can markedly reduce tropospheric delay when certain atmospheric sensors are used.

The following chart provides the absolute positioning technology total error estimates and the total error of differential technology at different intervals of distance between the customer and the differential station.

误差源 1	绝对导航误差(米) 2	3 差分导航误差(米)				
		0 公里 4	180 公里 4	900 公里 4	1800 公里 4	3600 公里 4
空间部分 5						
·钟差 6	3	0	0	0	0	0
控制部分 7						
·星历误差 8	3	0	0.1	0.5	0.9	1.8
·精度控制(SA) 9	27	~	~0	~0	~0	~0
传播 10						
·电离层延时 11	8	0	2.2	4.8	6.4	8.2
·对流层延时 12	2	0	1.8	1.8	1.8	1.8
用户部分 13						
·接收机噪声(滤波后) 14	1	1	1	1	1	1
·多径(直达波) 15	~0	~0	~0	~0	~0	~0
用户等效距离误差 16						
·UERE(rms)	28.6	1	3	5.2	6.7	8.6

1. Error source. 2. Absolute navigation error (meters). 3. Differential navigation error (meters). 4. Kilometers. 5. Space components. 6. Clock error. 7. Control components. 8. Satellite orbital error. 9. Precision control (SA). 10. Transmission. 11. Ionosphere delay. 12. Troposphere delay. 13. Customer component. 14. Receiver noise (post filtering). 15. Multipath (direct wave). 16. Customer equivalent distance error.

3. Space differential scheme

GPS navigation applications in space often signify that the various customers are a long distance apart. According to what was stated the section above, there are certain difficulties in using differential technology in space navigation. The high degree of error decorrelation will markedly reduce the effectiveness of using differential technology in space.

As for applications in space, it is generalized accepted that absolute navigation precision is already sufficient. In addition to this low precision space application, there are several other missions certain special stages of which require extremely high

position precision. Two of these special conditions requiring high precision are:

(1), Space ship rendezvous and docking operations.
(2), Reentry operations.

For the first situation, when the distance is very great absolute navigation can be used. When the two space ships are less than 10 kilometers apart in the final stags of rendezvous, differential (relative) navigation is used. The second situation requires use of several special technologies, and since the customer and the differential station are far apart, it is still possible for differential technology to play its role.

4. GPS used in rendezvous and docking operations

The use of GPS in the rendezvous operations between two space ships can be viewed as a special application of differential principles. Under these conditions, the two receivers are travelling along a certain orbit in space, and neither of the two space vehicles can find its own location by another method. During rendezvous it is necessary to know precisely the relative positions and velocity of the two space vehicles. Using absolute GPS navigation it is possible to determine with relatively low degree of precision the absolute dynamic state. Therefore, this special application of differential technology is no longer based on the corrected values of receivers, but the relative values are determined based on one of the following calculation methods.

(1). Using the absolute navigation of the two space vehicles, obtaining the relative state vectors from the differences in the absolute state vectors.

(2). Use special calculation methods to directly process the differences in the absolute observed values from the receivers of the two space vehicles, and then further calculate the relative dynamic state vectors.

The second solution signifies that errors in observed values are reduced before estimates are processed. Therefore, it is possible to determine the relative dynamic vectors even more precisely. Actually, because the two receivers are fairly close together, by subtracting the absolute observed values of the same GPS satellite subset, it is possible to eliminate all common errors effecting these observed values.

The relative measurement values obtained from this type of differential operation are far more precise that absolute measured values, and dynamic state vectors meet the precision requirements for distance and relative velocity for rendezvous operations, that is, distance precision of five meters and relative velocity precision of 0.1 meters per second.

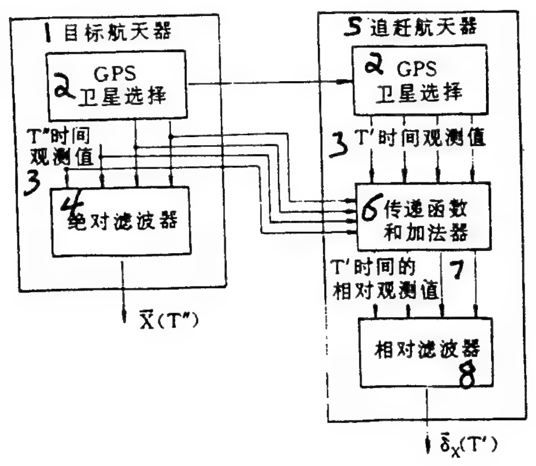
Figure 6 shows a method with a Karmann Filter as the main element, which processes all observed values observed by both space vessels. This method requires taking several signals from one space vehicle and transmitting them to the other space vehicle over a special data link. The primary information sent from the first space vehicle (target) to the second space vehicle (pursuer) includes the observed values and the observed GPS satellite subset. The pursuing space vehicle will use its own observed values taken from the same satellite subset and form a "relative observed value", and calculate the relative navigation data. Solving for this type of relative navigation requires the following conditions be met.

(1). The target and pursuing space vehicle must measure the observed values from the same GPS satellite subset.

(2). The target and pursuing space vehicle must use the same instant to update the GP S satellite orbital data.

(3). The target and pursuing space vehicles GPS receivers must be in time sync with the GPS system.

Fig. 6 Relative navigation: Relative observed value calculation



1. Target space vehicle. 2. GPS satellite selection. 3. Observed value at time T". 4. Absolute wave filter. 5. Pursuing space vehicle. 6. Transmission factor and adder. 7. Relative observed value at time T'. 8. Relative wave filter.

When using observed values for pseudo-ranging and pseudo-ranging rate of change, the target space vehicle chooses the GPS satellite, and sends a group of information towards the pursuing space vehicle including:

(1). The recognition code of the GPS satellite selected. (2). The observed pseudo-ranging value. (3). The observed pseudo-

distance change rate. (4). The observed time. (5). Attitude data.

The pursuing space vehicle will process this data with its own observed values for pseudo-ranging and pseudo-ranging change rate, obtaining the absolute state vector and the relative state vector. The target space vehicle observed values should be extrapolated to the pursuing space vehicle observed value corresponding observation time to compute the difference in observed data at the same time. Therefore, the two space vehicle's absolute observed values cannot be simply used to find the difference to obtain the relative observed values.

If the observations of the two customers are not synchronous, it is quite possibly due to one or more of the following reasons:

(1). The clocks are out of sync.

(2). Transmission time delay to the two customers is not the same.

(3). The customers are not the same distance from the GPS satellite.

(4). It is necessary to consider the transmission time delay for observed values to be transmitted from the target space vehicle to the pursuing space vehicle.

The instantaneous time of transmission of the GPS signal by the GPS satellite is defined as **T_r**, the pursuit space vehicle receives this signal at time **T'** and the pursuing space vehicle receives the same signal at time **T"**. By expanding the target space vehicle observed values at time **T"** and then calculating its observed values for time **T'**, it is possible to obtain the various GPS satellite observed values.

$$PR_2(T') = PR_2(T'') + \frac{\partial PR_2}{\partial t}\bigg|_{T''}(T' - T'')$$

In this equation, PR_2 expresses the target space craft's pseudo-ranging observed value.

Based on the hypothesis above,

$$T' - T'' = \Delta T_{B'} - \Delta T_{B''} + (\Delta\rho' - \Delta\rho'' + R' - R'' + d)/C$$

In this equation:

$\Delta T'_B$ is the customer clock deviation (i=',").

C is the speed of light

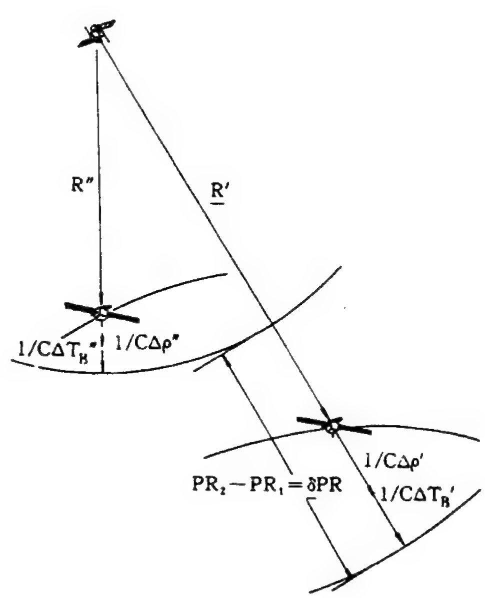
$\Delta\rho'$ is the ionosphere delay

R^i is the distance from the customer to the GPS satellite

d is the distance between the two customers

The primary item in the equation above is the customer clock deviation. Other items can be ignored. Figure 7 shows the relative geometry of pseudo-ranging.

Fig. 7 Relative geometry of pseudo ranging



The item $\frac{\partial PR_2}{\partial t}\Big|_{T''}$ is the target space vehicle pseudo-ranging change rate, that is: $RR_2(T'')$.

However, because of the existence of error, the measured value time derivative is not the same as the measured value of the derivative. However, considering the order of magnitude of the difference in these values, this difference can be ignored. Therefore, the relative pseudo-ranging observed value can be written as follows:

$$\delta PR(T') = PR_2(T'') - PR_1(T') - \varepsilon_R$$

In this equation,

$$\varepsilon_R = (T' - T'')PRR_2(T'')$$

The observed value of the relative pseudo-ranging rate of change is also like this.

Under such conditions, the time derivative measured value of the pseudo-ranging rate of change required to calculate the correction items is not available aboard the space craft. However, this item is especially small and can be ignored. Therefore, the measured value of the relative pseudo-ranging rate of change for each GPS satellite is:

$$\delta PRR(T') = PRR_2(T'') - PRR_1(T')$$

This measured value serves as the input to the "relative" Karmann filter for estimating the relative dynamics of the space vehicles.

Below we present the results obtained from software simulation in order to evaluate the capabilities which can be achieved by the relative navigation technology proposed in this article.

At the present time two small model spaceships in the same

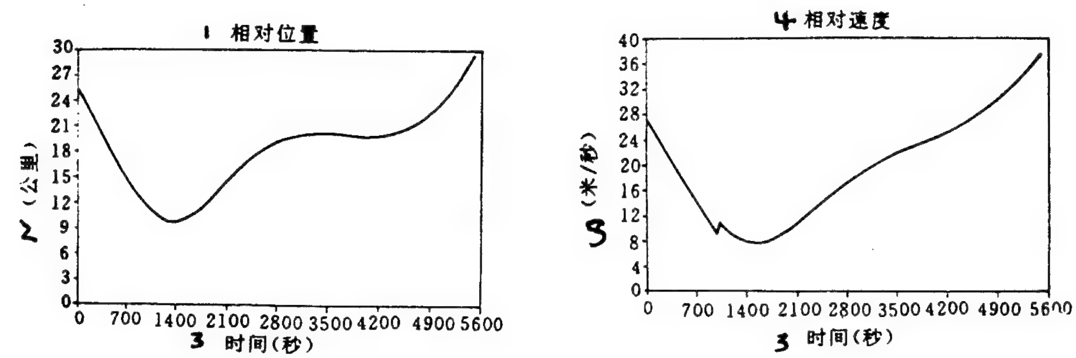
orbit are being studied for ANTARES (one possible scheme for the ASI task for the ERODE ITALSPAZIO scheme). Their primary characteristics are:

(1). Weight = 300 kilograms. (2). Windward area = 2.5 meters. (3). Atmospheric coefficient of resistance = 2.2.

Assume that GPS is composed of 21 satellites, operating on C/A code, ignoring any SA effect. Even if SA exists, its effects could be eliminated by using differential technology, so it would not effect the system capabilities.

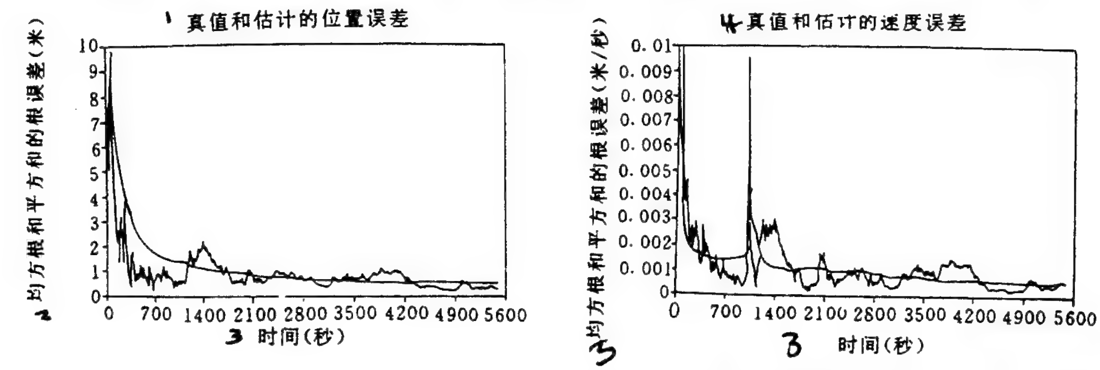
The basic orbit of the target space vehicle would be a circular orbit at 350 kilometers and an inclination of 2.5 degrees. The pursuing space vehicle orbit would be somewhat higher. In order to form relative motion, assume the pursuing space vehicle fires 50 newtons retro engines along its own velocity vector. Figure 8 provides the relative dynamics formed, and Figure 9 provides the relative positional error using this method. In the figures, the error of the RMS (root mean square) estimated by the Karmann filter is more regular than the RSS (root square sum), with RSS reflecting the actual error coming from random error sources. With the exception of the powered stage, the relative position error is less than two meters. The relative velocity error is less than two centimeters per second. These values completely satisfy the requirements for rendezvous operations.

Fig. 8 Relative position and velocity formed by powered pursuit



1. Relative position. 2. Kilometers. 3. Time (seconds). 4. Relative velocity. 5. Meters per second.

Fig. 9 Relative navigation: Precision capabilities



1. Positional error of true value and estimated value. 2. RMS and RSS error (meters). 3. Time (seconds). 4. Velocity error of true value and estimated value. 5. RMS and RSS error (meters per second).

IV. Using GPS for reentry differential navigation

The second application in space for GPS differential technology is for recovering experimental capsules (such as the CARINA capsule of Aeritalia). These capsules ordinarily use GPS for absolute navigation, but at certain stages (especially when SA exists) higher precision is required. During the reentry state, especially precise control of the space vehicle's position in space

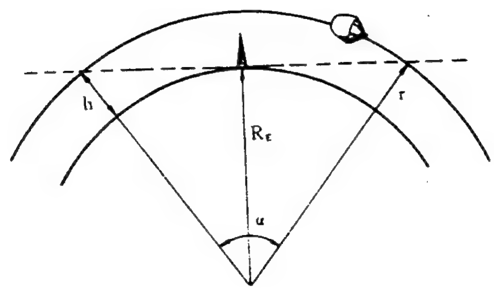
is of the utmost importance because this can allow it to leave its orbit at the proper point in orbit to ensure it lands accurately at the designated area.

Although space vehicle attitude is the most important parameter of reentry mechanics, the location at which it leaves orbit also plays an important role in determining the landing zone. With the GOS navigation system it is possible to constantly correct the attitude parameters and when the space vehicle has passed through the communications black obstacle zone caused by the ionosphere, it is possible to provide the necessary information to avoid landing in a populated area which would endanger life and property.

The final stage of landing can be an exception. The relative distance between the space vehicle and the differential station is normally several hundred kilometers. Under these conditions, as we have stated earlier, there will be a high degree of error decorrelation because of the space interval. Because of the serious degree of error decorrelation it is very difficult to estimate the system error components of such things as SA, satellite clock and orbit errors. It is also very difficult to separate then out from transmission errors.

According to Figure 10, at an altitude of 300 kilometers the space vehicle passes through the field of view of the differential station in 520 seconds. This station has an angle of elevation of 0°~90° and then 90°~0°. The angle of elevation from the observation station to the GPS satellite is of utmost importance for the atmospheric delay model. Under these conditions, there are marked differences in angle of elevation between the capsule's position and the differential station.

Fig. 10. Relative geometry of reentry capsule and differential station



Transmission errors of signals within the earth's atmosphere are much more sensitive to spacial decorrelation that other system errors. Based on this, a reasonable solution for reentry applications of differential technology is for the differential station reference receiver to be isolated from the effects of the various different error sources through a special Karmann filter. This type of Karmann filter can estimate and separate system error and transmission error. At the same time the filter processing can reduce random noise of the reference receiver.

Differential station total calculation error ε_d can be broken down as follows:

$$\varepsilon_d = \varepsilon_{GPS} + \varepsilon_{tropo} + \varepsilon_{iono}$$

Here, ε_{GPS} = GPS system error, ε_{tropo} = tropospheric delay, and ε_{iono} = ionospheric delay.

If during the reentry process the capsule receives from the reference station the total error estimated value ε_d, and this is used to correct the absolute observed value, it will not improve positioning precision. It is possible to use the differential station wave filter to estimate the i^{th} satellite pseudo-ranging and pseudo-ranging change rate observed value system error $\mathbf{b}_i$ and

$\mathbf{b}_i$.Also, it is also possible estimate the characteristic factors of the ionosphere and troposphere delays. These do not depend on the angle of elevation of the satellite, so it is possible to maintain its value at a fairly great distance.

The state vectors provided by the Karmann filter sent from the differential station to the capsule is shown in the following equation.

$$\vec{X} = [\Delta R_{tropo}, \Delta R_{iono}, b_1, \dot{b}_1, \cdots, b_N, \dot{b}_N]$$

The system errors $\mathbf{b}_i$ and $\mathbf{b}_i$ are directly used on the observed values for the pseudo-ranging and pseudo-ranging rate of changed measured by the GPS receiver inside the capsule, and tehn based on the prearranged model, $\Delta \mathbf{R}_{tropo}$ and $\Delta \mathbf{R}_{iono}$ are used to calculate the tropospheric and ionospheric delays.

This method markedly reduces the effect or error decorrelation caused by the increase in distance between the capsule and the differential station. However, it requires the sending of a group of data which is different from the differential navigation RTCM 104 standards. It seems that two types of information have to be sent. Only the first type is the same as the information content stipulated by RTCM. The first type of information includes pseudo-ranging and pseudo-ranging rate of change error correction value (as shown in Figure 11). The second type of information is designed for space application. This type of information includes the station location, the ionosphere and troposphere factors (as shown in Figure 12). The first type of information must be transmitted using a fairly high repeat frequency to ensure the correlation of the correction values and the observed values of the capsule receiver. The second type of information may be send at a frequency of once every minute, with the required data transmitted at a rate of 50 bits per second.

Fig. 11 First type of information format

1 2 3	4 5 6 7 8	9 10 11	12 13 14 15 16	17 18 19	20 21 22 23 24 25	26 27 28 29 30	比特编号 5
1 卫星健康参数	卫星识别码 2	3 伪距修正值				4 奇偶校验	字 3,8,13 或 18
距离变化率修正值 6		数据发布 7		卫星健康参数 8	9 卫星识别码	10 奇偶校验	字 4,9,14 或 19
13 伪距修正值				14 伪距变化率修正值		奇偶校验	字 5,10,15 或 20
15 数据发布		卫星健康参数 16	卫星识别码 17	伪距修正值(字节如上) 18		奇偶校验	字 6,11,16 或 21
19 伪距修正值(字节如上)		20 距离变化率修正值		21 数据发布		奇偶校验	字 7,12,17 或 22
距离变化率修正值 22		数据发布 23		填充 24		奇偶校验	字 N+2 如果 N_s = 1,4,7 或 10 25
数据发送 26		27 填充				奇偶校验	字 N+2 如果 N_s = 2,5,8 或 11 25

1. Satellite health factors. 2. Satellite recognition code. 3. Pseudo-ranging correction value. 4. Parity check. 5. Bit number. 6. Correction value for ranging rate of change. 7. Data distribution. 8. Satellite health parameters. 9. Satellite recognition code. 10 parity check. 11. Bit. 12. If. 13. Pseudo-ranging correction value. 14. Pseudo-ranging rate of change correction value. 15. Data distribution. 16. Satellite health parameters. 17. Satellite recognition code. 18. Pseudo-ranging correction value (bytes same as above). 19. Pseudo ranging correction value (bytes as above). 20. Ranging rate of change correction value. 21 Data distribution. 22. Ranging rate of change correction value. 23. data distribution. 24. Filler. 25. If. 26. Data transmission. 27. Filler.

Fig. 12 Second type of information format

1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30	
ECEF-X 坐标分量 1			2 奇偶校验	3 字 3
ECEF-X 坐标分量 1	ECEF-Y 坐标分量 1		2 奇偶校验	3 字 4
ECEF-Y 坐标分量 1		ECEF-Z 坐标分量 1	2 奇偶校验	3 字 5
ECEF-Z 坐标分量 1			2 奇偶校验	3 字 6
折射率 4	对流层延时 5	电子含量 6	2 奇偶校验	3 字 7

1. Coordinate vector. 2. Parity check. 3. Bit. 4. Refractivity. 5. Tropospheric delay. 6. Electron content.

In order to evaluate the capabilities of this technology, a computer simulation was performed on the CARINA capsule mission. The primary physical characteristic parameters of the CARINA capsule are:

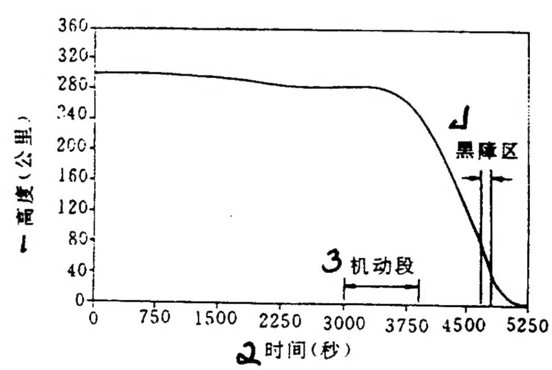
(1), Weight = 520 kilograms.

(2), Windward area = 1.32 square meters.

(3), Atmospheric coefficient of resistance = 2.2.

At first, a circular orbit at 300 kilometers was studied, and then the powering out of orbit. The changes in altitude of this space vehicle is shown in Figure 13. Assuming that during normal operations the capsule used absolute navigation technology. The differential station must be below the preset point of powering out of orbit in order to provide differential operations during the limiting sector drop.

Fig. 13. Altitude cross section during CARINA capsule reentry

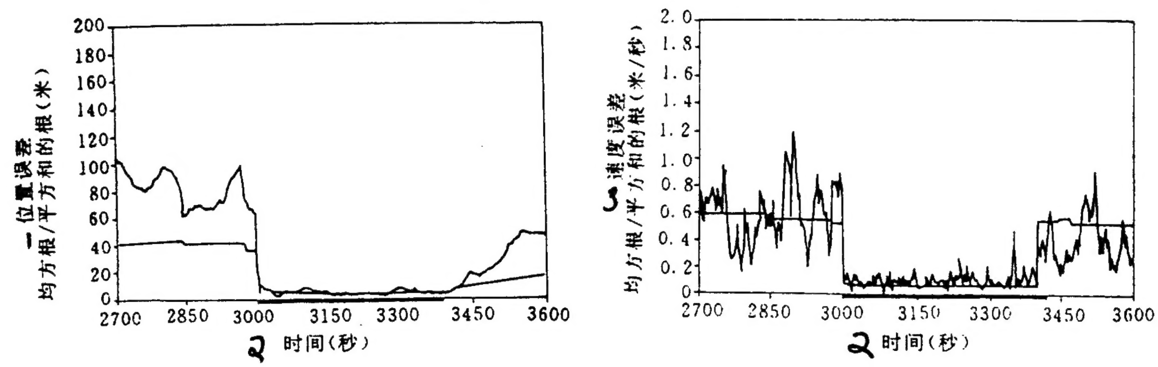


1. Altitude (kilometers). 2. Time (seconds. 3. Powered section. 4. Black obstacle zone.

Figure 14 shows the comparative precision improvement of the absolute method and using the differential method of determining the CARINA capsule dynamic state vectors. Assuming the addition of SA, then it's effect would be completely eliminated with

differential technology.

Fig. 14



1. Positional error RMS/RSS (meters). 2. Time (seconds). 3. Velocity error RMM/RSS (meters per second).

VI. Conclusions

The purpose of this research topic is to explore the feasibility of using GPS navigation technology is certain special space missions. Absolute navigation technology is a powerful tool for space vehicle autonomous navigation, and some problems will be generated in differential navigation technology because the distance between the two customers becomes greater.

This article has already demonstrated that in certain stages of space missions it is possible to use a differential scheme. however, it is necessary to make some necessary modifications of the basic technology. The results of simulation of the reentry stage of the CARINA capsule and the ERODE-ANTARES experimental rendezvous stage indicate that by using differential technology it is possible to make absolute and relative dynamic states determined more accurately than with traditional navigation technology.